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Telepresence Control of a Dual-Arm Dexterous Robot

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ABSTRACT

Telepresence is an approach to teleoperation that provides egocentric, intuitive interactions between an operator and a remote environment. This approach takes advantage of the natural cognitive and sensory-motor skills of an on-orbit crew and effectively transfers them to a slave robot. A dual-arm dexterous robot operating under telepresence control has been developed and is being evaluated. Preliminary evaluation revealed several important observations that suggest the directions of future enhancement.

INTRODUCTION

The current approaches to robot teleoperation in the Space Shuttle as well as the International Space Station Alpha (ISSA) are based on "joystick" type hand controllers. The visual feedback is provided by multiple cameras, many of which are mounted on the robot arms. This approach to teleoperation is similar to the cock-pit design of fighter aircraft. For manipulator control, this approach can be counter-intuitive, and may overload the visual and manual capacities of the operator. The problem becomes even more amplified when the slave robot is not designed to reflect the degree of dexterity the human operator possesses. As a result, the operator's skill is not effectively transferred to the slave robot. A different approach to robot teleoperation is *telepresence*. In telepresence, the master control and feedback devices are designed to maximize the use of the operator's innate cognitive and sensory-motor skills [1][2].

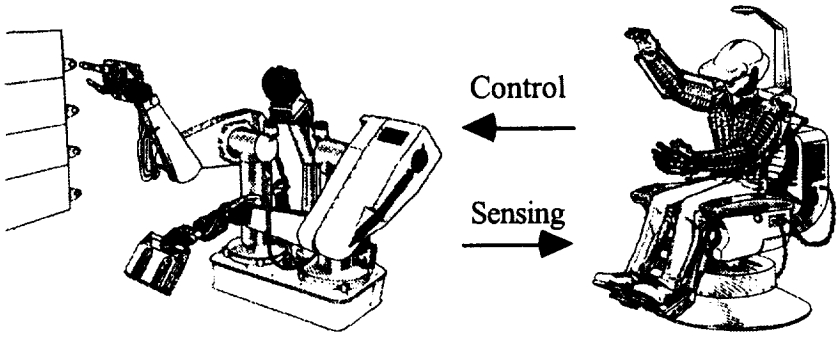
The following describes the Phase I activities of an evolving robotics testbed at the NASA Johnson Space Center (JSC). The testbed system, called the Dexterous Anthropomorphic Robotic Testbed (DART), has telepresence as its baseline operating mode. Ultimately, DART will be operating under *shared control*, where telepresence control of the robot will be augmented by intelligent automation. DART is controlled by the Full Immersion Telepresence Testbed (FITT), the interface to the human operator [2].

PHASE I OBJECTIVE

The DART Phase I objective is to develop, demonstrate, and optimize a baseline telepresence system. The steps to achieve this goal include: (1) developing a dexterous telerobotic system with telepresence control; (2) developing a flexible, modular, shared control architecture; and (3) conducting comparative evaluation of telepresence versus other types of controls. The following will primarily focus on the activities leading to the accomplishment of Step (1) and (2). Preliminary evaluations, in partial fulfillment of Step (3), will also be described.

SYSTEM OVERVIEW

Most telepresence applications require at least two functional components: *master* and *slave*. The master component is usually the operator's telepresence interface, and the slave is usually an emulator of the master. In our setup, FITT acts as the master that controls DART, the slave robot. The FITT and DART systems are shown conceptually in figure 1.



(a) (b)

Figure 1. Telepresence control of a dual-arm dexterous robot. (a) The Dexterous Anthropomorphic Robotic Testbed. (b) The Full-Immersion Telepresence Testbed (concept drawing).

Full-Immersion Telepresence Testbed

FITT provides intuitive control of DART. This testbed immerses the operator in the robot's environment and links human and robot motions and senses as transparently as possible to provide a natural feel to the operator. The FITT system includes interfaces for controlling DART's head camera unit, arms, hands, and base. A Virtual Research™ helmet displays DART's stereo camera images with a 100 degree field of view. The depth perception provided with stereo imaging is one of the testbed's most important immersion features. A Polhemus™ tracker located on the top of the helmet commands the orientation of DART's head camera unit. The same type of sensor is also attached to each of the operator's wrists, providing full 6 degree-of-freedom (DOF) control of the robotic arms. EXOS™ hand masters worn by the operator provide gripper and joint level finger control in dexterous teleoperation.

Dexterous Anthropomorphic Robotic Testbed

DART, shown in figure 2, includes several robotic devices, controllers, and supporting workstations. The robotic arms are PUMA 562's with an 8.8 pound payload capability. Each arm also has a force-torque sensor. On the right arm is a Stanford/JPL hand. Each finger has a urethane fingertip to provide a high static friction surface and can be hyper-extended to provide a large manipulation envelope. On the left arm is a parallel jaw gripper. The head camera unit that provides video feedback to the teleoperator supports 3 DOF rotations and contains two color CCD cameras. The driver level software is executed on two Tadpole™ multiprocessor systems. Each multiprocessor system has four M88000 processors and runs a multiprocessor version of the UNIX operating system. The vision system is implemented on a DataCube™ pipeline image processor board.

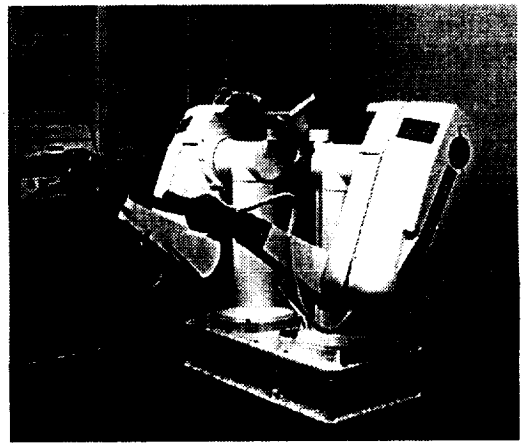


Figure 2. The Dexterous Anthropomorphic Robotic Testbed (DART).

The DART system is controlled via a modular, distributed control architecture as shown in figure 3. Each subsystem spans one or more processes. The subsystem processes are distributed across three separate computers, networked on an Ethernet backbone. The subsystems communicate and are synchronized by high-level communication software called the Tele-Robotics Interconnection Protocol (TelRIP) [4]. This architecture provides a flexible environment for development, maintenance, and future enhancements. FITT controls DART by linking to this Ethernet backbone and commanding the subsystems

through TelRIP. The router process, denoted by R, is responsible for transmitting data to the appropriate subsystem processes.

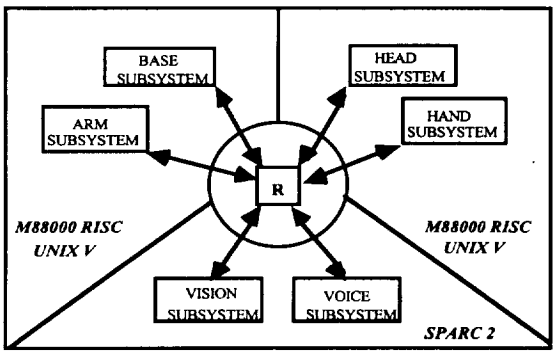


Figure 3. DART's distributed control architecture.

PRELIMINARY EVALUATIONS

Preliminary evaluations of the DART and FITT systems are currently being performed using operators of varying skill levels, ranging from several years of robotic experience to absolutely no engineering experience. This allows the intuitiveness of operation to be qualitatively evaluated. The tasks range from inspection to object handling to dexterous manipulation.

Inspection tasks are comprised mainly of bringing an object towards the head camera and viewing it from different angles. These tasks provide information about the required display resolution, stereo perception, as well as the effect of working with *egocentric* views of the workspace. The object handling tasks include picking up objects of various sizes and shapes (*e.g.*, balls, pipes, tools) and placing them at a different location, and handing objects back and forth between the dexterous hand and the gripper. Some of the dual-hand dexterous tasks performed are tying a knot with a rope, folding and unfolding a thermal blanket, and manipulating an electronic task panel which contains toggle and rocker switches, push buttons, sliders, and a dial. These tasks reflect some of the basic dexterity and skills required for on-orbit extra- and intra-vehicular activities (EVA/IVA).

OBSERVATIONS

One of the most significant observations from the preliminary evaluations is the short time it takes a new operator to become proficient with the system. For example, operators with no previous experience were able to transfer objects between the two hands and manipulate the controls on the panel within a 30 minute session. Operators with considerable experience in "cock-pit" type control have also found the training time greatly reduced due to the intuitiveness of the motion controls and the immersiveness of the visual feedback.

The weight of the exoskeleton hand masters causes muscle fatigue when the system is used for long duration. This limitation presents some difficulties when it is necessary to maintain a specific position for a long period of time. This observation suggests the need for a mechanism that will allow the operator to re-adjust his or her arm positions (*e.g.*, indexing).

While teleoperation of the dexterous hand offers much flexibility for grasping, it was found inadequate for manipulation. The difficulty lies in the inability of the operator to preshape the hand and execute manipulation primitives, such as turning and pinching, in a consistent manner.

The operator can experience mild motion sickness when using the system due to a slight delay between the motions of the operator's head and the DART camera system. This only occurs when the operator makes large, quick head movements. Motion sickness usually occurs whenever there is a significant mismatch between the robot's and the operator's rate of motion. Motion sickness can also be caused by unintended body and head movements. However, since the operator rarely has to make large head movements once focused on a task, this problem is not a major prohibiting factor.

Although the current system provides the necessary visual cues to perform many tasks, a few limitations of the visual feedback have been observed. The visual feedback the operator receives is coarse (320 X 240 pixels) and the distance between the head cameras is a little too narrow, so the depth perception of the operator is not optimal. These visual limitations can have serious impacts on the operator's performance. For example, since FITT currently does not offer force-reflection, the operator assesses the force imparted onto the environment by watching for the amount of physical compliance. The active compliance of the DART's fingers is very useful in this regard.

Another problematic area encountered is the transformation of human hand motions to DART's hand motions. Several transformation methods were explored [3]. These methods included joint-to-joint mapping, forward and inverse kinematics transformations, and a combination of joint and Cartesian control. The two major difficulties encountered when applying these techniques are the dissimilar kinematics of the human's and DART's hands, and the slight changes in the sensor positions when the gloves are taken off and put back on. Joint-to-joint mapping was chosen as the method of control due to the computational simplicity and the intuitiveness of the control.

The telepresence evaluations also revealed some interesting operator behaviors. For example, an initial *exercise* is desirable before each session to familiarize the operator with the system's behavior. The exercise typically involves having the operator command the robot's arms, hands and head in various different ways to explore the dexterity of the robot. Without the exercise, less experienced operators often have the tendency to move like a robot, not fully utilizing his or her natural coordination skill. After a few training sessions, the operator generally will learn to compensate for any kinematics dissimiliarities between the operator and the robot.

FUTURE WORK

The results of our initial evaluation have pointed out several areas for improvement. The exoskeleton gloves will be replaced by light-weight Cybergloves™ to reduce fatigue. A position indexing mechanism will be implemented to allow the operator to reposition his or her arms while the robot remains still. Grasp and manipulation primitives modulated by operator's hand movements will be developed for tasks that require a high degree of accuracy and control. A second generation head camera unit will be fabricated to provide a tighter head tracking and to correct the narrow interpupilary distance. A high-resolution (640 X 480 pixels) head-mounted displays will be sought to improve operator's visual acuity.

A force-reflective dexterous arm master, developed by EXOS™, will be integrated with FITT to evaluate the effect of force-reflection. Additional evaluations will be conducted to quantify the performance of the DART/FITT system. New test subjects will be recruited to study the correlation between training-time versus performance, and the performance of "cock-pit" type control versus telepresence.

CONCLUSION

Telepresence is *not* a new idea. It is, however, an idea that is becoming a reality due to the recent advances in head-mounted display, dexterous glove controller, motion trackers, force-reflective masters, and other human compatible interactive devices. The DART and FITT combination represents an integration of these telepresence technologies for space robotics applications. Many lessons were learned in our preliminary evaluations. While several areas for improvement were identified, the benefit of telepresence in space robotics is clearly evident by the variety of complex tasks DART/FITT can perform under the control of an operator with minimal training.

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